PCT
WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E21B 47/10	A1	(11) International Publication Number: WO 99/45235 (43) International Publication Date: 10 September 1999 (10.09.99)

(21) International Application Number: PCT/EP99/01397

(22) International Filing Date: 4 March 1999 (04.03.99)

(30) Priority Data:
60/077,023 6 March 1998 (06.03.98) US

(71) Applicant *(for all designated States except CA)*: SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V. [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL).

(71) Applicant *(for CA only)*: SHELL CANADA LIMITED [CA/CA]; 400 - 4th Avenue S.W., Calgary, Alberta T2P 2H5 (CA).

(72) Inventor: SMITH, David, Randolph; 861 White Oak Drive, Bellville, TX 77418 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: INFLOW DETECTION APPARATUS AND SYSTEM FOR ITS USE

(57) Abstract

There is provided a method for monitoring fluid flow within a region to be measured of a subterranean formation, said method comprising placing at least one source within said subterranean formation; placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source; and providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

INFLOW DETECTION APPARATUS AND SYSTEM FOR ITS USE

Field of the Invention

This invention relates to a method for measuring fluid flow in a subterranean formation; in particular measurements of flow rates of liquids, gases, and mixed fluids in subterranean formations.

Background

Recent developments in the oil drilling industry of well bore construction techniques such as horizontal wells and multi-lateral wells, present new challenges to the completion and reservoir engineering disciplines. High rate horizontal wells in deep water conditions further push the technology tools the petroleum engineer has available to safely and prudently produce the reservoirs.

Classical methods of reservoir monitoring assume the permeability ("K") and height ("H") of the zone contributing to the production of the well is known. This "KH" is often confirmed with production logs on a periodic basis and is typically considered constant. The KH of a well is paramount for most reservoir calculations. In a horizontal well or a multi-lateral well, the H of the well bore penetrating the reservoir is known from electric logging methods, and more recently by logging while drilling techniques. However, the logged reservoir interval may not be the same as the H actually contributing to the well production and, in fact, the H may change with time.

The industry has adopted a laze faire attitude relating to the assumption of inflow performance in horizontal and multi-lateral wells. Grand assumptions regarding inflow well performance are made based on

surface data (i.e. flow rates, pressures, water cut, etc.), possible down hole pressure gauges, and rules of thumb. The reality is that these assumption can lead to poor well performance, poor reservoir management, completion equipment failures, and in the worst cases, catastrophic failure of the well.

The only method currently available to the reservoir or production engineer to monitor changes or losses in "H" is to run a wire line or tubing deployed production log during well interventions. These logs are difficult to interpret, particularly in horizontal and high angle wells. This is due to the flow meters inability to measure the 3 phase flow rates, often referred in the literature as water hold up or gas blow by. This procedure of production logging requires a rig mobilization, resulting in lost production during the rig up and rig down of the logging equipment, and presents a risk of loosing equipment in the well. Production logging is not always possible (e.g. some subsea completions or wells in which an electrical submersible pump (ESP) is installed). Moreover, since the production logging data is subject to interpretation, the decision to run the production-logging suite is often avoided. The end result is that the production is maintained by increasing the choke size at the surface. This can result in more damage, and ultimately in screen and well bore failures or large hydrate production and blowouts.

Summary of the Invention

The method of the invention provides a means for monitoring fluid flow directly within a region to be measured of a subterranean formation, said method comprising:

placing at least one source within said subterranean formation;

placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source;

providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

There is also provided a method for monitoring fluid flow in a region to be measured of a well bore, while the well bore is on-line, said method comprising:

placing at least one source selected from a thermal source, an acoustic source, and combinations thereof within said region to be measured;

placing at least one sensor selected from a thermal sensor, an acoustic sensor, and combinations thereof within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said sources;

providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

Detailed Description

The method of the invention provides a means for monitoring the flow of fluid, wherein fluid means liquids or gases or mixtures of liquids and gases, from subterranean formations. Measurement takes place directly in the region where a measurement is desired. In the case of a flowing well, the measurements may be taken while the well is producing. Thermal and/or acoustic sources are placed in the fluid flow path and sensors capable of detecting temperature or acoustic

changes placed near the sources detect changes to the fluid caused by the sources.

One embodiment of the invention provides a method for monitoring fluid flow within a region to be measured of a subterranean formation. At least one source is placed within the formation. Placement is relatively permanent, meaning the source is set and then left in the measurement zone. At least one sensor is also placed within the region to be measured. Each sensor should be adjacent to one or more sources, in close enough proximity to measure changes to the fluid caused by the source(s). It is necessary to also provide at least one means for transmitting data from the sensors to at least one data collection device. The data collection device may be subterranean, on the surface, or in the air but it must be capable of communicating with an operator. As used herein, an operator may be an object, such as an operating station, or a human.

The sources may be optical sources, electrical heat sources, acoustic sources, or combinations thereof. Examples include thermisters, optical heaters, continual heating elements, electric cables, sonar generators, and vibration generators. Because it is optimum to limit restrictions in the formation, the preferred sensors are optical fibres, which are small enough to be non-intrusive. The optical fibres may also act as the data transmission means, thereby serving two purposes. The sources and the sensors are preferably oriented perpendicular to the fluid flow.

When the subterranean formation is a well, the fluid flow region to be measured is typically within the well bore, be it vertical, horizontal or deviated. A means for deploying the sensors and data links in a fairly non-intrusive manner is via hollow tubular members.

The system of the invention is expected to perform well using applied well technology known as Micro Optical Sensing Technology ("MOST"). MOST allows for the miniaturization of sensing equipment in submersible equipment. Fundamentally, oil and gas well environments have restricted geometry and hostile conditions of temperature and pressure. MOST is able to function in these environments due to it's ability to use very small diameter data links (optic fibres) and to use sensors that can withstand temperatures above 200 °C.

Since the sources, sensors and data links are permanently installed in the desired region of the formation, there is no need for well interventions, such as production logging. The method can provide a continual inflow performance profile of the formation on a real time basis and multiple flow detection nodes along the formation can be monitored.

The use of thermal sources and sensors will be used as an example. A series of electrically or optically powered heat sources may be placed along a well bore axis parallel to a series of thermal sensors. The thermal sources may be in many forms, including but not limited to single point heating elements like thermisters, optical heaters, or a continual heating element like electric cable.

The heat sensors are preferably single or multiple optic fibres. The fibres may be deployed into the well in multiple means and in multiple geometry. An example of deployment which will protect the fibres from hydrogen exposure is to arrange the temperature sensors and data links in small hollow members, such as tubes. The flow detection system is formed by placing the optic fibres in the flow stream before the heaters, after the heaters, or both. Other embodiments uses the optic fibres and heaters deployed parallel to one another, surrounding one

another in coil configurations, and many other geometry's. The preferred embodiment places the heat source and thermal sensors perpendicular to the fluid flowing in the well bore, such that the heat source heats the fluid while the thermal sensors measure the heat change in the fluid stream flowing over the heat source. This system then forms a series of classic thermal flow meters according to the following simplified heat flow equation:

$$Q = Wc_p \ (T_2 - T_1)$$

where

Q = heat transferred (BTU/Hr);

W = mass flow rate of fluid (lbm/Hr); and

c_p = specific heat of fluid (BTU/lbm °F).

The accuracy of the flow meter is dependent on the accuracy of specific heat data for the flowing fluids. The specific heat of the fluids in the well will change with time, flowing pressures, and reservoir conditions (e.g. coning).

Optimum well production requires the heat sources and temperature measurement devices to be small and non-intrusive to the well bore inside diameter. Non-intrusive deployment allows for the well to be fully opened and thus allows for stimulation, squeeze, or logging techniques to be performed through the completion with the sources, sensors and data links permanently installed.

The preferred sensors and/or data links of the invention are optic fibres. Optic fibres are exotic glass fibres which are available with many different coatings and by various different manufacturing methods that affect their optical characteristics. Optic fibres have a rapid decrease in functionality when exposed to hydrogen, and of course subterranean water is a readily available hydrogen carrier. Therefore the fibres must be

placed in a carrier. But other characteristics of optic fibres allow one fibre to read multiple changes along the fibre's length, an obvious advantage.

Fibers may be used in oil and gas wells in conjunction with Optical Time Delay Reflectometry ("OTDR") devices (commonly referred to as "intrinsic measurement"). Intrinsic sensing along the fibre is done with application of quantum electrodynamics ("QED"). QED relates to the science of sub-atomic particles like photons, electrons, etc. For this application, interest is in the photons travelling through a very special glass sub-atomic matrix. The probability, or probability amplitude, of the photon interacting with a silicon dioxide sub atomic structure is known for each specialized optic fibre. The resulting back scattering of light as a function of thermal affects in the glass subatomic structure has a very well known relationship to the index of refraction of the optic fibre. Knowledge of the power and frequency of the light being pumped, or launched down the optic fibre allows for calculation of the predicted light and frequency emitted or back scattered at a given length along the optic fibre.

The process of the invention uses OTDR and thermal and/or acoustic sources to measure flow in wells. Flow changes at each node may be monitored versus time, providing a qualitative measurement on a permanent basis in real time. Knowing the glass and laser light being used, a back scattering returning power can be measured with "OTDR" according to the following equation:

$$P_{bs}(l) = \tfrac{1}{2} P_0 \Delta t v_g C_s NA^2 \exp\left(\int -2\alpha dx\right)$$

where

P_{bs} = backscattering power returning from distance l;

P_0 = launch power;

Δt = source time pulse width, in time units;

v_g = group velocity;

C_s = scattering constant;

NA = numerical aperture of fibre; and

α = total loss of attenuation coefficient.

OTDR can successfully and very repeatable measure the back scattering changes as a function of temperature caused by a laser pulsed light wave down an optic fibre, by relating Cs to and α.

$$C_s \cong (\alpha_r)_{co} + (\alpha_s)_{co} + P_c/P_t\ (\alpha_s)_d$$

and

$$\alpha = \alpha_{co} + P_c/P_t\ (\alpha_d)$$

where

α_r = Raman scattering coefficient;

α_s = Rayleigh scattering coefficient;

$(\ )_{co}$ = parameter associated with fibre core;

$(\ )_{cl}$ = parameter associated with fibre cladding; and

P_{cl}/P_{total} = ratio of total power exists in cladding due to evanescent wave effects.

The OTDR equipment uses a laser source, an optic fibre; a directional coupler connected to the fibre, an optoelectronic receiver, signal processing, and data acquisition equipment.

The method of the invention allows simple actions to be performed downhole without surface intervention, and allows reservoir performance downhole to be monitored using 4D seismic and other technologies. The present invention may also be applied to other flow processes (i.e. pipelines, refining processes, etc.). It will be apparent to one of ordinary skill in the art that many changes and modifications may be made to the invention without departing from its spirit or scope as set forth herein.

CLAIMS

1. A method for monitoring fluid flow within a region to be measured of a subterranean formation, said method comprising:

placing at least one source within said subterranean formation;

placing at least one sensor within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said source;

providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

2. A method according to claim 1 wherein said source is selected from an optical source, an electrical heat source, an acoustic source, and combinations thereof.

3. A method according to claim 2 wherein said source is selected from a thermister, an optical heater, a continual heating element, an electric cable, a sonar generator, a vibration generator, and combinations thereof.

4. A method according to claim 1 wherein said sensor is one or more optical fibres.

5. A method according to claim 1 wherein said one or more sensor and said one or more source are oriented perpendicular to said fluid flow.

6. A method for monitoring fluid flow in a region to be measured of a well bore, said method comprising:

placing at least one source selected from a thermal source, an acoustic source, and combinations thereof within said region to be measured;

placing at least one sensor selected from a thermal sensor, an acoustic sensor, and combinations thereof within said region to be measured, wherein each said at least one sensor is adjacent to at least one source such that said sensor measures changes to said fluid caused by said sources;

providing at least one means for transmitting data from each said at least one sensor to at least one data collection device, said at least one data collection device capable of communicating with an operator.

7. A method according to claim 6 wherein said source is selected from an optical source, an electrical heat source, an acoustic source, and combinations thereof.

8. A method according to claim 7 wherein said thermal source is selected from a thermister, an optical heater, a continual heating element, an electric cable, a sonar generator, a vibration generator, and combinations thereof.

9. A method according to claim 6 wherein said sensor is one or more optical fibres.

10. A method according to claim 9 wherein said sensors and data links are deployed in hollow tubular members.

11. A method according to claim 6 wherein said one or more sensor and said one or more source are oriented perpendicular to the fluid flow in said region to be measured of said wellbore.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 99/01397

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B47/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 0 442 188 A (TEXACO DEVELOPMENT CORP) 21 August 1991 see abstract see page 2, column 1, line 1 - line 21 see page 3, column 3, line 32 - column 4, line 30; claim 1	1-3,6,7 4,9,11
X	EP 0 481 141 A (TEXACO DEVELOPMENT CORP) 22 April 1992 see abstract see page 2, column 1, line 1 - line 35 see page 2, column 2, line 4 - line 10 see page 3, column 3, line 42 - column 4, line 31; claims 1,2	1-3,6,7

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 June 1999	05/07/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lorne, B

2

International Application No
PCT/EP 99/01397

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X Y	FR 2 707 697 A (FIS) 20 January 1995 see page 2, line 30 - page 3, line 23 see page 6, line 20 - page 7, line 11; claims 1,2; figure 4B	1-3,5 11
Y	EP 0 508 894 A (SCHLUMBERGER LTD ;SCHLUMBERGER TECHNOLOGY BV (NL); SCHLUMBERGER HO) 14 October 1992 see abstract see page 2, column 1, line 1 - line 11 see page 2, column 2, line 20 - line 36 see page 3, column 4, line 37 - line 54; claims 4,7,9-11	4,9
A	US 5 208 650 A (GIALLORENZI THOMAS G) 4 May 1993 see column 1, line 5 - line 13 see column 2, line 50 - line 56; claims 1-3	8
A	US 5 493 626 A (SCHULTZ PHILIP K ET AL) 20 February 1996 see column 1, line 10 - line 13 see column 3, line 46 - column 4, line 6; claim 1	10

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

In ational Application No
PCT/EP 99/01397

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0442188	A	21-08-1991	US	4905203	A	27-02-1990
EP 0481141	A	22-04-1992	US	4982383	A	01-01-1991
			DK	481141	T	03-10-1994
FR 2707697	A	20-01-1995	NONE			
EP 0508894	A	14-10-1992	FR	2675202	A	16-10-1992
US 5208650	A	04-05-1993	NONE			
US 5493626	A	20-02-1996	CA	2140748	A	08-12-1994
			EP	0656127	A	07-06-1995
			NO	950217	A	20-03-1995
			WO	9428450	A	08-12-1994

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : E21B 47/10, 36/04, 47/06, 47/12	A1	(11) International Publication Number: **WO 00/11317** (43) International Publication Date: 2 March 2000 (02.03.00)

(21) International Application Number: PCT/US99/19781

(22) International Filing Date: 25 August 1999 (25.08.99)

(30) Priority Data:
60/097,783 25 August 1998 (25.08.98) US

(71) Applicant *(for all designated States except US)*: BAKER HUGHES INCORPORATED [US/US]; Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: WILLIAMS, Glynn [GB/GB]; Roman House, Northway, Walworth Industrial Estate, Andover, Hampshire SP10 5QD (GB). NEUROTH, David, H. [US/US]; 18305 South 4185 Road, Claremore, OK 74017 (US). DALRYMPLE, Larry, Verl [US/US]; 5650 S.E. Roden Road, Claremore, OK 74017 (US).

(74) Agents: ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).

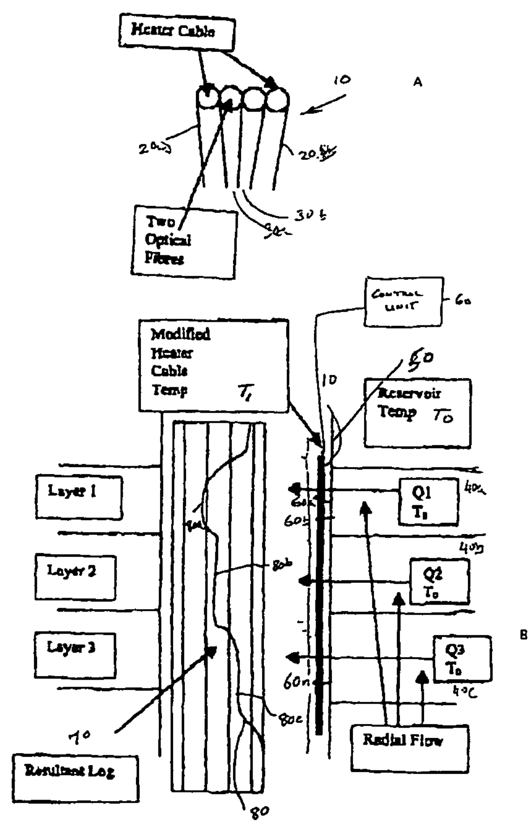
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD OF USING A HEATER WITH A FIBER OPTIC STRING IN A WELLBORE

(57) Abstract

The present invention provides a heater cable (10) that may be deployed in a wellbore to elevate the temperature of the wellbore above the temperature of the surrounding fluid and the formation. One or more fiber optic strings are included in or are carried by the heater cable. The heater cable carrying the fiber optics is placed along the desired length of the wellbore. At least one fiber optic string measures temperature of the heater cable at a plurality of spaced apart locations. Another string may be utilized to determine the temperature of the wellbore. In one aspect of this invention, the heater cable is heated above the temperature of the wellbore. The fluid flowing from the formation to the wellbore lowers the temperature of the cable at the inflow locations. The fiber optic string provides measurements of the temperature along the heater cable. The fluid flow is determined from the temperature profile of the heater cable provided by the fiber optic sensors.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

METHOD OF USING A HEATER WITH A FIBER OPTIC STRING IN A WELLBORE

1. Field of the Invention

This invention relates to utilizing fiber optic sensor strings with heater cables for use in oil wells and more particularly for determining the flow of formation fluid into the wellbore and to control the operation of the heater cables for optimum operations.

2. Background of the Art

Heater cables are often used in wellbores to increase the temperature of the fluid in the wellbore to prevent the formation of paraffins and to prevent the oil from flocculating. Such phenomena cause at least some of the oil to become highly viscous, and often plugs the perforations. Such fluids can clog the electrical submersible pumps. Heater cables are also used to heat the formation surrounding the wellbores which contain heavy (highly viscous) oil to reduce the viscosity of such oil.

The heater cable usually is a resistance heating element. High current supplied from the surface can heat the cable to a temperature substantially higher than the formation temperature. In ESP applications, a heater current

may be deployed below the ESP. In other production wells, heater cable may be installed along any desired portion or segment of the wells. It is desirable to determine the fluid flow from various production zones along a wellbore and to monitor and control the temperature of the heater cable so as to heat the wellbore only as required for optimum recovery and to reduce power consumption.

U.S. Patent 4,435,978 discloses a hot wire anemometer in which heat is supplied at a constant rate to a sensor element with fluid flowing past the element. The drop in temperature of the sensor element is used to give a measurement of the fluid flow. This method accurately measures the flow under a variety of flow conditions.

U.S. Patent Ser. No. 5,551,287 discloses a wireline device in which a hot film anemometer deployed on sensor pads measures the temperature of fluid entering the borehole. The fluid flowing past the sensor element produces a change in resistance that is used in a bridge circuit to give a measurement of temperature. This temperature measurement, when combined with a measurement of local ambient temperature, gives an indication of the rate of fluid flow into the borehole. U.S. Patent 4,621,929 discloses a fiber optic thermal anemometer using a sensor element with temperature sensitive optical properties.

The present invention is an apparatus and method for monitoring the fluid flow from a producing well with a plurality of producing intervals. A cable that includes a number of fiber optic thermal anemometer sensors is deployed in the producing well with the sensors in the vicinity of the perforations in the casing or inlets from which fluid from the reservoirs enters the production casing. The present invention also provides temperature distribution along the heater cable length which information is utilized to control the operation of the heater cable.

SUMMARY OF THE INVENTION

The present invention provides a heater cable that may be deployed in a wellbore to elevate the temperature of the wellbore above the temperature of the surrounding fluid and the formation. One or more fiber optic strings are included in or are carried by the heater cable. The heater cable carrying the fiber optics is placed along the desired length of the wellbore. At least one fiber optic string measures temperature of the heater cable at a plurality of spaced apart locations. Another string may be utilized to determine the temperature of the wellbore. In one aspect of this invention, the heater cable is heated above the temperature of the wellbore. The fluid flowing from the formation to the wellbore lowers the temperature of the cable at the inflow locations. The fiber optic string provides measurements of the temperature along the heater cable. The fluid flow is determined from the temperature profile of the heater cable

provided by the fiber optic sensors. In another aspect of this invention, the temperature distribution along the heater cable is used to cntrol the operation of the heater cable to maintain the elevated temperature within desired limits. The heater cable may be selected turned on and turned off to provide only the desired amount of heat. This may be accomplished by selectively turning on and turning off the heater cable or by increasing and decreasing the electric power supplied as a function of the downhole measured temperatures.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

FIG. 1A shows a portion of a heater cable carrying fiber optic strings according to the present invention.

FIG. 1B shows the cable of **FIG. 1A** deployed in a producing borehole that penetrates a number of reservoirs.

FIG. 2 shows a heater cable deployed in a wellbore being controlled by

a control unit as a function of the temperature measurements provided by the fiber optic sensors in the cable.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1A** shows a portion of a cable **10** according to one embodiment of the present invention. It includes a heater cable **20** that carries electrical current and is used as a source of heat by means of uniformly dispersed resistive elements within a portion of the cable (not shown). The cable also includes a pair of fibers **30a, 30b** for carrying optical signals down the borehole and back up the borehole and for measuring temperature at spaced locations along the fibers.

FIG. **1B** shows the cable **10** deployed in a producing borehole **50** that penetrates a number of reservoirs. For illustrative purposes, three producing intervals **40a, 40b** and **40c** are shown. For illustrative purposes only, each of the three producing intervals is assumed to have a uniform temperature of T_0. Further, each of the three producing intervals has a different rate of flow, denoted by Q_1 , Q_2 , Q_3 , of reservoir fluid into the producing well **50**. A plurality of fiber optic sensors, **60a, 60b, 60c..... 60n** in the cable **10** make continuous measurements of temperature at the respective locations. To determine the flow rate from the various zones Q1-Q3, a control unit **60**

provides power to the heater cable **20**, to cause it to heat the wellbore **50** to a temperature T1 that is significantly higher than To. The fluid flowing from the zones **40a-40e**, which causes the temperature of the heater cable **20** to drop at the flow locations. Under these conditions, the greater the flow rate of fluid Q_i past a sensor, the greater the temperature of the sensor will drop from T_1 towards T_0. Measurements of temperature of the sensor are used as an indication of the flow of the formation fluid into the wellbore **50**.

The control unit **60** receives the signals from the fiber optic strings **30a-30b** and can be programmed to calculate the fluid flow from each zone. A log such as shown by the resultant log **70** may be continuously displayed and recorded by the control unit **60**. The log **70** shows a temperature profile along the well **50**. An example of the affect on the temperature curve **80** of the flow from zones **Q1-Q3** respectively is shown at locations **80a-80c**.

Fig. 2 shows a heater cable **100** made according to the present invention, deployed or placed in a wellbore **110** having a casing **112**. The cable **100** includes one or more fiber optic string **120** adapted to measure temperature at spaced apart locations **T1-Tn** along a segment or portion of the cable **100** shown by the dotted line. The heater cable **100** is adapted to heat any desired segment of the cable. For convenience, the heater cable herein is assumed to carry heating elements that heat the segment from **T1-Tn**. A power unit **130**

supplies power to the heating element **111**. A control unit **140** controls the power unit **130**, and an optical energy and data unit **142**.

The heater element **111** is heated to a predetermined temperature to enhance production flow to the surface. The fiber optic string continuously provides the temperature profile along the wellbore via sensor **T1-Tn**. If the temperature of the cable **100** in the wellbore is outside a predetermined norm, the control unit **140** adjusts the power to the cable **100** until the heater cable temperature provided by **T1-Tn** falls back in the desired limits. The control unit may be programmed to selectively turn on and turn off the heater cable to optimize the power consumption and to enhance the operating life of the heater cable.

The heater cable **100** may be deployed below an electrical submersible pump (ESP) when used as shown in **Fig. 2** and also above the ESP. The temperature distribution **T1-Tn** along the heater cable is also useful in predicting heater cable **100** failures. It provides indication of hot spots in the heater cable and the efficiency of the cable corresponding to the input power.

Since the current supplied to the heater element **111** is the same, the heat generated by a uniform heater element will be uniform. The temperature distribution **T1-Tn** can thus provide indication of the quality of the heater cable's

110 performance.

While the foregoing disclosure is directed to the preferred embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

WHAT IS CLAIMED IS:

1. A method of determining flow of fluid from a formation into a wellbore, comprising:

providing a heater cable with a fiber optic string adapted to measure temperature at selected spaced apart locations along said heater cable;

placing said heater cable along a segment of said wellbore that is receiving fluid from adjacent formation;

heating the heater cable to a temperature above the temperature of the wellbore at said selected segment;

measuring a temperature profile along said heater cable by said fiber optic string; and

determining from said temperature profile flow of fluid from said formation into the wellbore.

2. The method of Claim 1 further comprising:

providing a control unit at the surface for receiving temperature measurements from said fiber optic string.

3. The method of Claim 2 further comprising:

providing a temperature log of said wellbore from said temperature measurements.

4. A method of controlling the operation of a heater cable deployed in a wellbore, said heater cable heating a segment of said wellbore to enhance production of fluids through the wellbore, said method comprising:

providing a heater cable with a fiber optic string adapted to measure temperatures at spaced apart locations along said heater cable;

deploying said heater cable at a selected location in said wellbore;

providing power to said heater cable to heat the wellbore to a first temperature;

measuring temperature at selected locations by the fiber optic string; and

adjusting the power to the heater cable as a function of the temperature measurements.

5. The method of claim 4 further comprising providing a control unit at the surface, said control unit controlling the supply of power to the heater cable as a function of the temperature measurements.

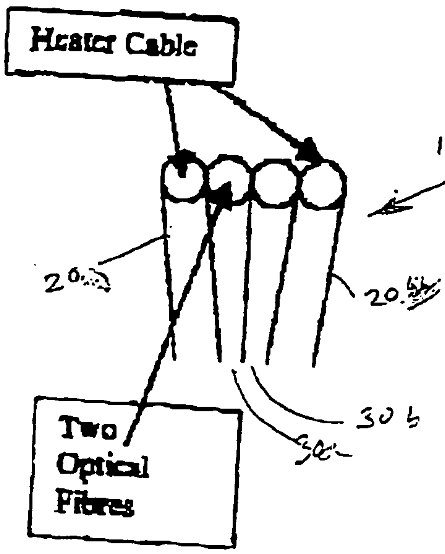

Heater Cable
10
20a
20b
Two Optical Fibres
30b
30a

FIG 1A

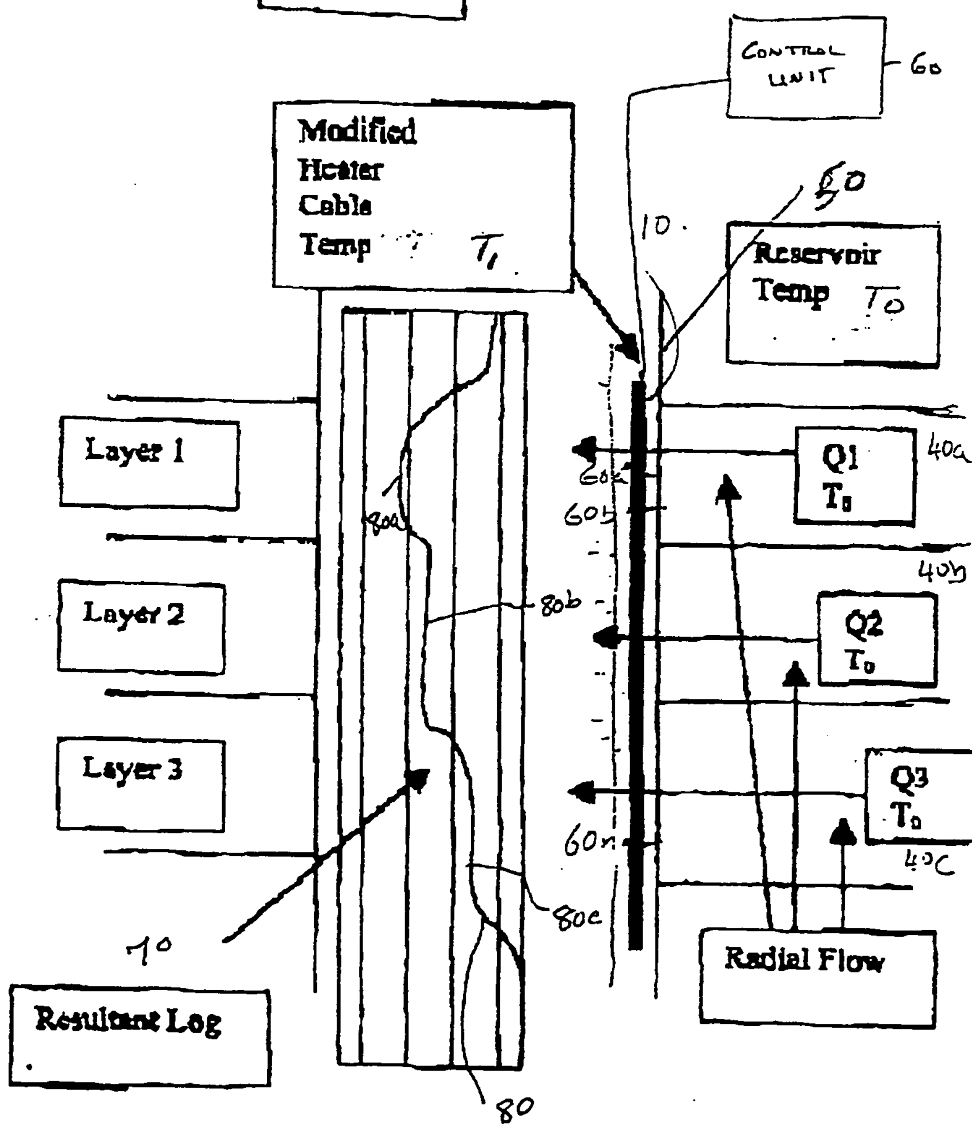

CONTROL UNIT
60
Modified Heater Cable Temp T_1
50
10
Reservoir Temp T_0
Layer 1
Layer 2
Layer 3
Q1 T_0
Q2 T_0
Q3 T_0
40a
40b
40c
60a
60b
60n
80a
80b
80c
70
80
Resultant Log
Radial Flow

FIG 1B

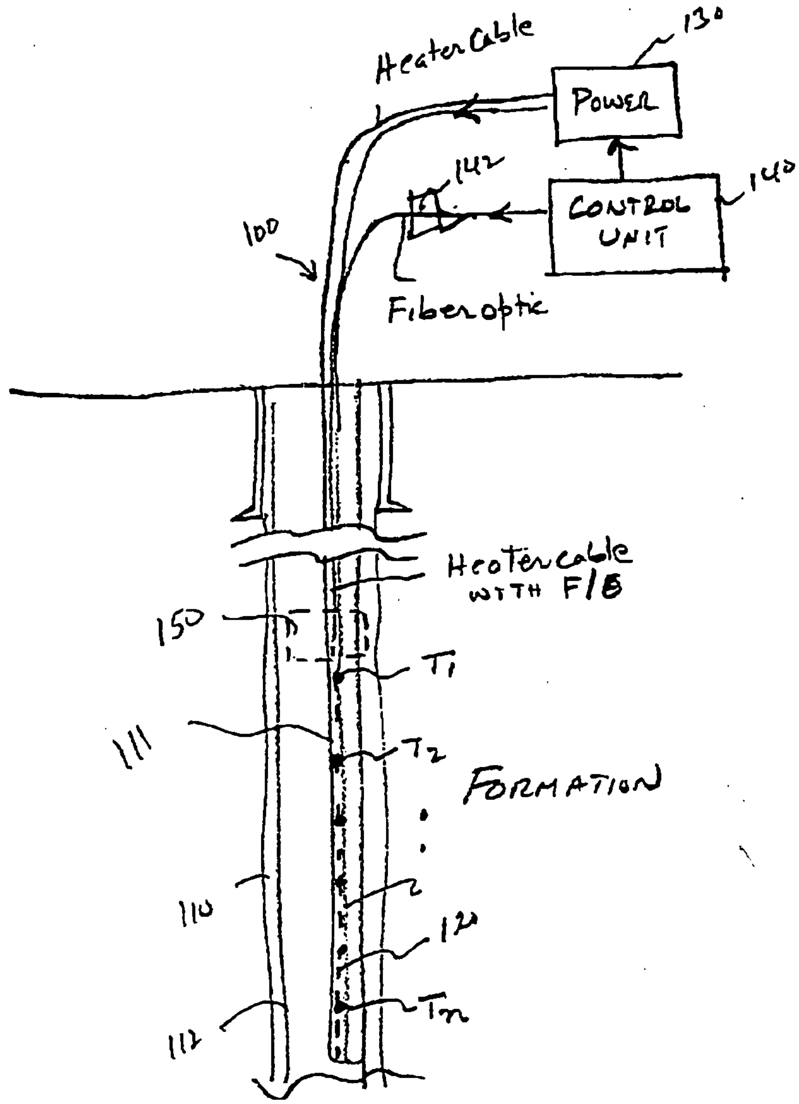

Heater Cable
130
Power
142
140
Control Unit
100
Fiberoptic
Heatercable with F/O
150
T1
111
T2
Formation
110
120
112
Tn

FIG 2

INTERNATIONAL SEARCH REPORT

Inte ional Application No
PCT/US 99/19781

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B47/10 E21B36/04 E21B47/06 E21B47/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO 99 45235 A (SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.) 10 September 1999 (1999-09-10) page 5, line 18 -page 6, line 6 page 6, line 28 - line 29 claims 3,4 page 4, line 14 - line 18 ---	1-5
A	US 5 582 064 A (KLUTH) 10 December 1996 (1996-12-10) claims 8,9,16 ---	1,4
A	WO 96 09461 A (SENSOR DYNAMICS LIMITED) 28 March 1996 (1996-03-28) abstract page 7, line 20 -page 8, line 8 --- -/--	1,4

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 January 2000	17/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Sogno, M

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/19781

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9945235	A	10-09-1999	NONE			
US 5582064	A	10-12-1996	AT	145058	T	15-11-1996
			AU	4268593	A	29-11-1993
			BR	9306311	A	30-06-1998
			CA	2118229	A	11-11-1993
			DE	69305845	D	12-12-1996
			DE	69305845	T	12-06-1997
			DK	638163	T	14-04-1997
			EP	0638163	A	15-02-1995
			WO	9322645	A	11-11-1993
			GB	2280752	A,B	08-02-1995
			NO	944144	A	31-10-1994
WO 9609461	A	28-03-1996	AU	3527195	A	09-04-1996
			GB	2307706	A,B	04-06-1997
			US	5804713	A	08-09-1998
US 4435978	A	13-03-1984	NONE			
US 5551287	A	03-09-1996	CA	2209918	A	08-08-1996
			EP	0807202	A	19-11-1997
			WO	9623957	A	08-08-1996
US 4296318	A	20-10-1981	IT	1159115	B	25-02-1987
			DE	2938312	A	10-04-1980
			FR	2436976	A	18-04-1980
			GB	2036302	A,B	25-06-1980
US 4832121	A	23-05-1989	CA	1296618	A	03-03-1992
			WO	8902972	A	06-04-1989
US 4621929	A	11-11-1986	AT	44614	T	15-07-1989
			CA	1230240	A	15-12-1987
			EP	0144630	A	19-06-1985
			JP	60098345	A	01-06-1985

INTERNATIONAL SEARCH REPORT

Inter onal Application No
PCT/US 99/19781

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 435 978 A (GLATZ) 13 March 1984 (1984-03-13) cited in the application column 1, line 63 - line 68	1,4
A	US 5 551 287 A (MAUTE) 3 September 1996 (1996-09-03) cited in the application column 3, line 8 - line 18	1,4
A	US 4 296 318 A (MEZZETTI) 20 October 1981 (1981-10-20) abstract	1,4
A	US 4 832 121 A (ANDERSON) 23 May 1989 (1989-05-23) abstract	1,4
A	US 4 621 929 A (PHILLIPS) 11 November 1986 (1986-11-11) cited in the application abstract	1,4

1